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INVESTIGATION OF THE SUBCRITICAL CRACK GROWTH LIFE OF TITANIUM IN A CORROSIVE ENVIRONMENT

G. J. PETRAK

University of Dayton Research Institute

TECHNICAL REPORT AFML-TR-68-271

OCTOBER 1968

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AFML-TR-68-271

INVESTIGATION OF THE SUBCRITICAL CRACK GROWTH LIFE OF TITANIUM IN A CORROSIVE ENVIRONMENT

G. J. PETRAK

FOREWORD

This report was prepared by the University of Dayton Research Institute, Dayton, Ohio. The work was performed under USAF Contract No. F33(615)-67-C-1262. The contract was initiated under Project No. 7381, "Materials Applications," Task No. 738106, "Design Information Development," and administered by the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio, Mr. David C. Watson (NAAE), Project Engineer.

All (or many) of the items compared in this report were commercial items that were not developed or manufactured to meet Government specifications, to withstand the tests to which they were subjected, or to operate as applied during this study. Any failure to meet the objectives of this study is no reflection on any of the commercial items discussed herein or on any manufacturer.

This report covers work conducted from February 1967 to November 1967. The contractor's report number is UDRI-TR-68-35.

The report was submitted by the author in June 1968.

This technical report has been reviewed and is approved.

A Olevitch

A. OLEVITCH
Chief, Materials Engineering Branch
Materials Support Division
Air Force Materials Laboratory

ABSTRACT

This program was conducted to investigate the major factors influencing the stress corrosion cracking (SCC) of titanium in various environments under static and dynamic loads. Emphasis was on determining the influence of mechanical parameters (such as cyclic loading frequency, precracking stress level, and strain rate) on the resultant SCC property data. Ti-8Al-1Mo-1V in the duplex annealed condition was used in this investigation because of its relatively high sensitivity to SCC. Air, water, and 3.5 percent NaCl environments were used.

The results indicated that the precracking stress level will affect the static SCC data just as higher precracking stresses affect plane strain fracture toughness results. Under dynamic loads a lower cyclic frequency in a corrosive environment caused a longer cyclic life. The results also indicated that the same parameters recommended (ASTM-STP-410) for precracking fracture toughness specimens should be recommended in the preparation of stress corrosion (precracked) specimens.

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SECTION I

INTRODUCTION

In recent years the susceptibility of titanium alloys to stress corrosion cracking (SCC) has been the subject of many investigations. In particular, the Government has supported much effort on the problem in order to evaluate the usefulness of titanium alloys for application in aerospace and nautical vehicles. The phenomenon of SCC has been attributed to many mechanisms or combination of mechanisms such as chemical, electrochemical, and mechanical.

The current effort focused on the mechanical factors affecting SCC and the effect that such factors have on the resultant engineering properties of a titanium alloy. Center cracked fracture toughness and crack growth specimens of duplex annealed Ti-8Al-1Mo-1V were tested in three environments, statically and at three cyclic frequencies.

SECTION II

SPECIMENS

Specimens for this investigation were fabricated from a single 0.050 inch thick sheet of Ti-8Al-1Mo-1V in the duplex annealed condition procured from the Titanium Metals Corporation of America. The mechanical properties, chemical composition, and processing history as specified by the manufacturer are shown in Table I.

Tensile specimens for base line data were machined to the dimensions shown in Figure 1. The fracture toughness, static crack growth, and subcritical fatigue crack growth specimens were all of the same configuration which is shown in Figure 2. The long axis of all specimens was in the longitudinal direction of the sheet.

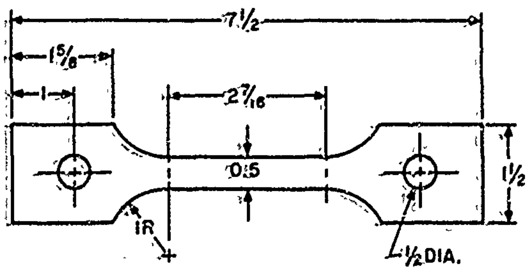

Figure 1. Tensile Specimen

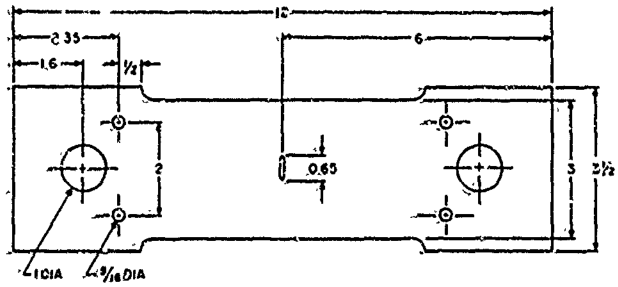

Figure 2. Fracture Toughness and Subcritical Crack Growth Specimen

TABLE I

MATERIAL PROPERTIES FROM MANUFACTURER OF Ti-8Al-1Mo-1V

Tensile

Direction	Yield Strength KSI	Ultimate Strength KSI	Elongation %
L	123.0	149.3	15.5
T	127.0	139.0	12.0

Chemical Composition (%)

C	0.022
Fe	0.07
N	0.009
Al	7.7
Va	0.9
Mo	1.0
H	0.004

Processing History

1. Ingot forged to sheet bar slab with final 50% reduction from 1950°F.
2. Sheet bar ultrasonically inspected, cropped, and conditioned.
3. Conditioned sheet bar rough rolled to intermediate size from alpha-beta field.
4. Roughdowns descaled, conditioned, and vacuum annealed at 1350°F to reduce hydrogen level.
5. Roughdowns finish rolled from 1700/1800F.
6. Re-squared and descaled sheets creep-flatten annealed at 1400°F / 15 min., AC.
7. Duplex annealed sheets descaled, ground, and pickled.
8. Tensile, bend, and hydrogen tests made.
9. Sheets inspected, re-squared to size, overall marked, crated and shipped.

SECTION III

TEST EQUIPMENT

The test equipment used in the investigation consisted of a Schenck fatigue machine with high and low frequency capability, a Wiedemann Universal Test machine with low frequency fatigue capabilities, and a Baldwin creep machine. Associated equipment consisted of a Wiedemann micro-former, an Automatic Timing and Controls, Inc. demodulator, and a Leeds and Northrup Co. recorder.

A plastic cup was placed around the specimens to contain the liquid environments. The cup was sealed with paraffin wax. See Figure 3.

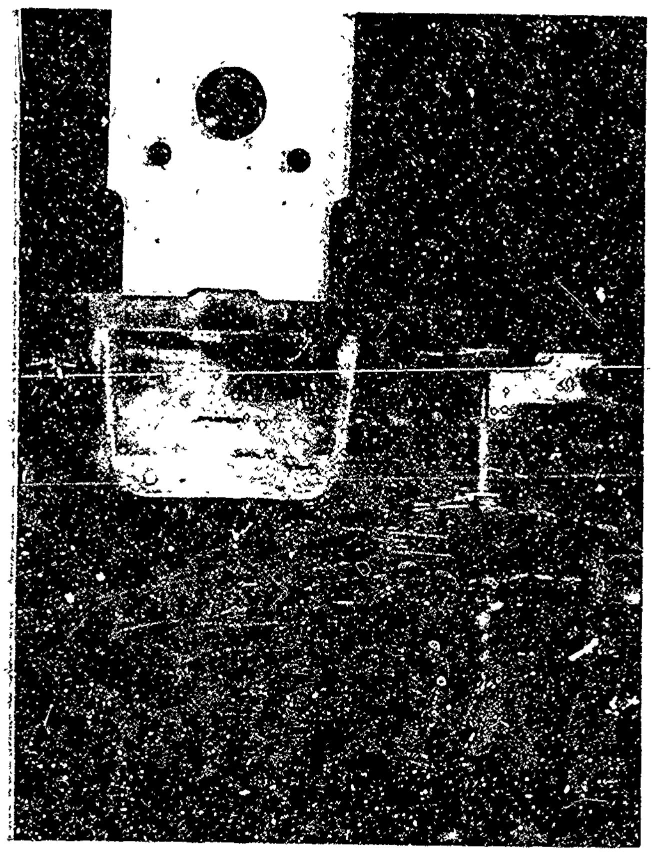

Figure 3. Instrumented Subcritical Crack Growth Specimen

SECTION IV

TEST PROCEDURE

Four types of basic tests were performed: tensile, moderate strain rate fracture toughness, static stress corrosion, and subcritical fatigue crack growth at various frequencies and in different environments. In order to monitor the crack growth of the static and fatigue specimens, a compliance technique was employed (see References 1 and 2). The calibration of the compliance gage was similar to that reported previously in Reference 2. Fracture toughness and subcritical fatigue crack growth specimens were precracked on the Schenck fatigue machine.

TENSILE TESTS

These tests were performed to insure the material met quality control specifications. The tests were run in the Wiedemann tensile machine at room temperature with a head movement rate of 0.05 inch per minute.

FRACTURE TOUGHNESS

The fracture toughness tests were run at two loading rates in an attempt to approximate the two slower rates at which the subcritical fatigue crack growth tests were performed. Loading rates of 109 and 1,300 KSI per minute were obtained. These tests were performed on the Wiedemann tensile machine at room temperature.

STATIC CRACK GROWTH

Static crack growth tests were run in the Baldwin creep machine. Initial stress intensity levels for the precracked specimens were close to the maximum intensity levels encountered at the initiation of subcritical fatigue crack growth. Tests were performed at room temperature in a 3.5 percent NaCl environment. Compliance was continuously monitored during the tests. The NaCl solution was not added until the specimen was completely loaded.

SUBCRITICAL FATIGUE CRACK GROWTH

These tests were performed on precracked panels on the Wiedemann machine at two cycles per minute (cpm) and on the Schenck machine at 40 and 1600 cpm. Three environments were used: ambient air, H_2O, and 3.5 percent NaCl solution. At the two lower frequencies, two and 40 cpm, compliance of the specimen was continuously monitored. At the higher frequency, 1600 cpm, crack length was monitored visually

by taping a scale to the specimen and recording the cycles as the crack propagated past the marks. All tests were run at a constant "R" ratio of 0.1 where "R" = σ min/σ max.

SECTION V

RESULTS

TENSILE TESTS

The results of the tensile tests are presented in Table II.

TABLE II

TENSILE DATA

Spec.	Ultimate Strength (KSI)	Yield Strength (KSI)	Elongation (%)
1	148.2	134.2	12.6
2	150.3	133.2	13.8
3	149.1	135.0	14.0
Avg.	149.2	134.1	13.5

FRACTURE TOUGHNESS

Fracture toughness tests were run to determine if higher loading rates would possibly cause an abrupt pop-in of the crack front. At room temperature for the thickness of material used in these tests, no pop-in is observed when testing at recommended loading rates. Since titanium alloys are strain rate sensitive, it was thought that a higher strain rate might allow less time for pertubation of the plastic zone at the tip of the crack and approach a plane strain condition with pop-in. No pop-in was observed at the two loading rates tested.

STATIC CRACK GROWTH

Static crack growth tests were run on two specimens in 3.5 percent NaCl solution with the results shown in Figure 4. Specimen 34 was fatigue cracked at a gross stress of 46 KSI and specimen 35 at 25 KSI.

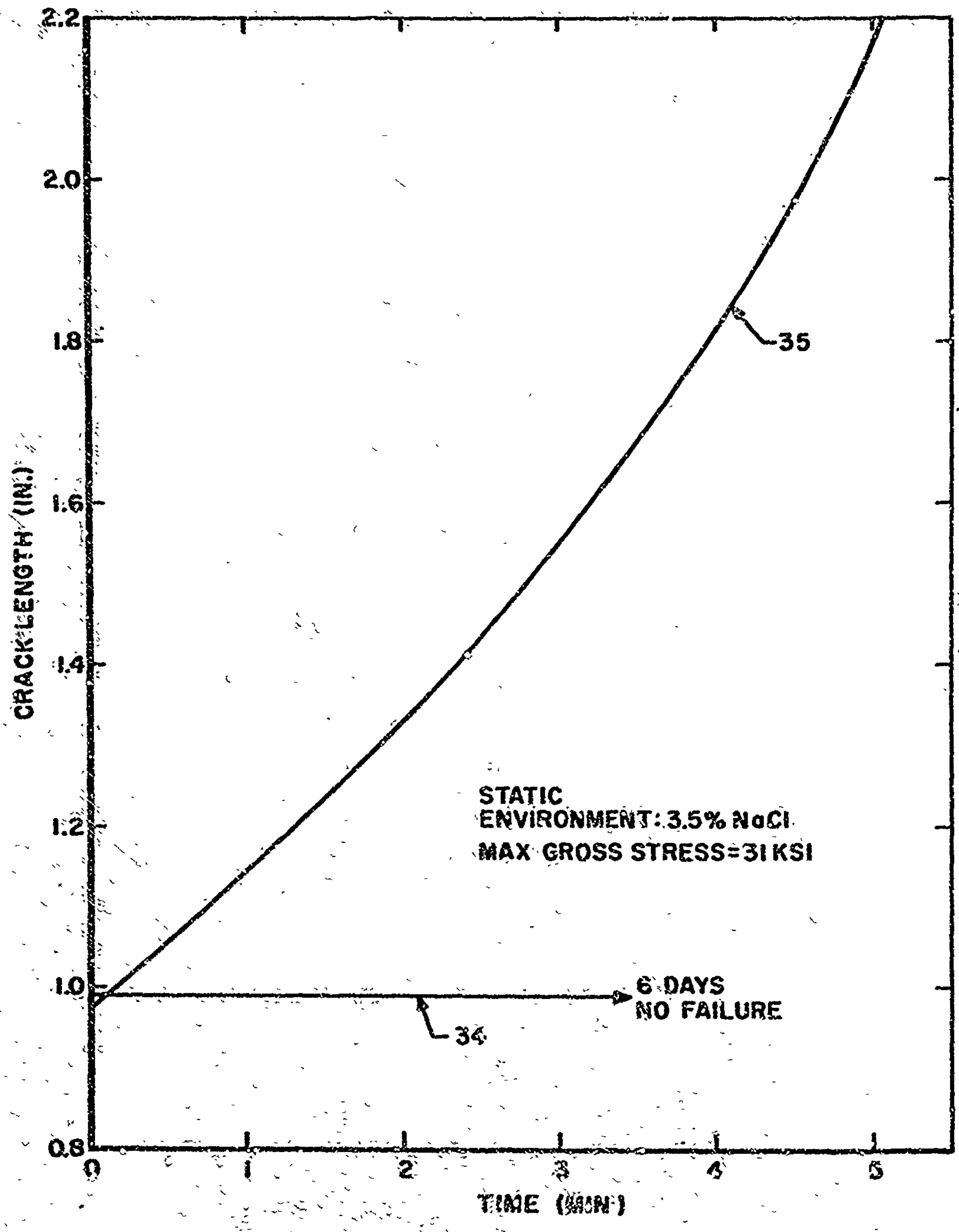

Figure 4. Crack Length vs. Time Under Static Loading

SUBCRITICAL FATIGUE CRACK GROWTH

Fatigue crack growth curves are as shown in Figures 5 to 7. All curves generated in a 3.5 percent NaCl solution are replotted on a single graph in Figure 5. Where more than one curve at a frequency exists, the average is plotted. Figures 6 and 7 are replots of the curves generated at 2 and 40 cpm, respectively, in the various environments.

SECTION VI

DISCUSSION AND ANALYSIS

FRACTURE TOUGHNESS

Since titanium alloys are strain rate sensitive, tests were run to determine if loading rates similar to those employed in subcritical fatigue crack growth tests would cause less perturbation of the strain field ahead of the crack (smaller plastic zone) and approach a plain strain condition. If indeed this was the case, a previously observed difference in the subcritical fatigue crack curves at different frequencies could be attributed to the stress state effect. Since no pop-in was observed in the tests, no conclusion can be drawn concerning the effects of loading rate on the mode of subcritical fatigue crack propagation.

STATIC CRACK GROWTH

The material used in this investigation appears to be SCC sensitive. One of the precracked specimens tested under static loading failed within six minutes after the introduction of 3.5 percent NaCl solution. The other statically tested specimen, which was also fatigue cracked but at a higher stress level, did not fail after six days in the same corrosive environment and stress level. This difference can be attributed to the sharpness of the cracks generated under the different fatigue cracking loads. Apparently the higher fatigue cracking loads produced a blunter crack front which would require a higher apparent plane strain stress intensity factor for crack initiation. This blunted crack inhibited SCC initiation in the one specimen. This behavior has been previously observed in fracture toughness testing and indicates the same procedures that apply to fracture toughness testing would be useful for precracking SCC specimens. (See Reference 3.)

SUBCRITICAL FATIGUE CRACK GROWTH

Referring to Figure 5, a definite frequency effect can be noted for specimens tested in a corrosive environment. Lower frequencies tend to

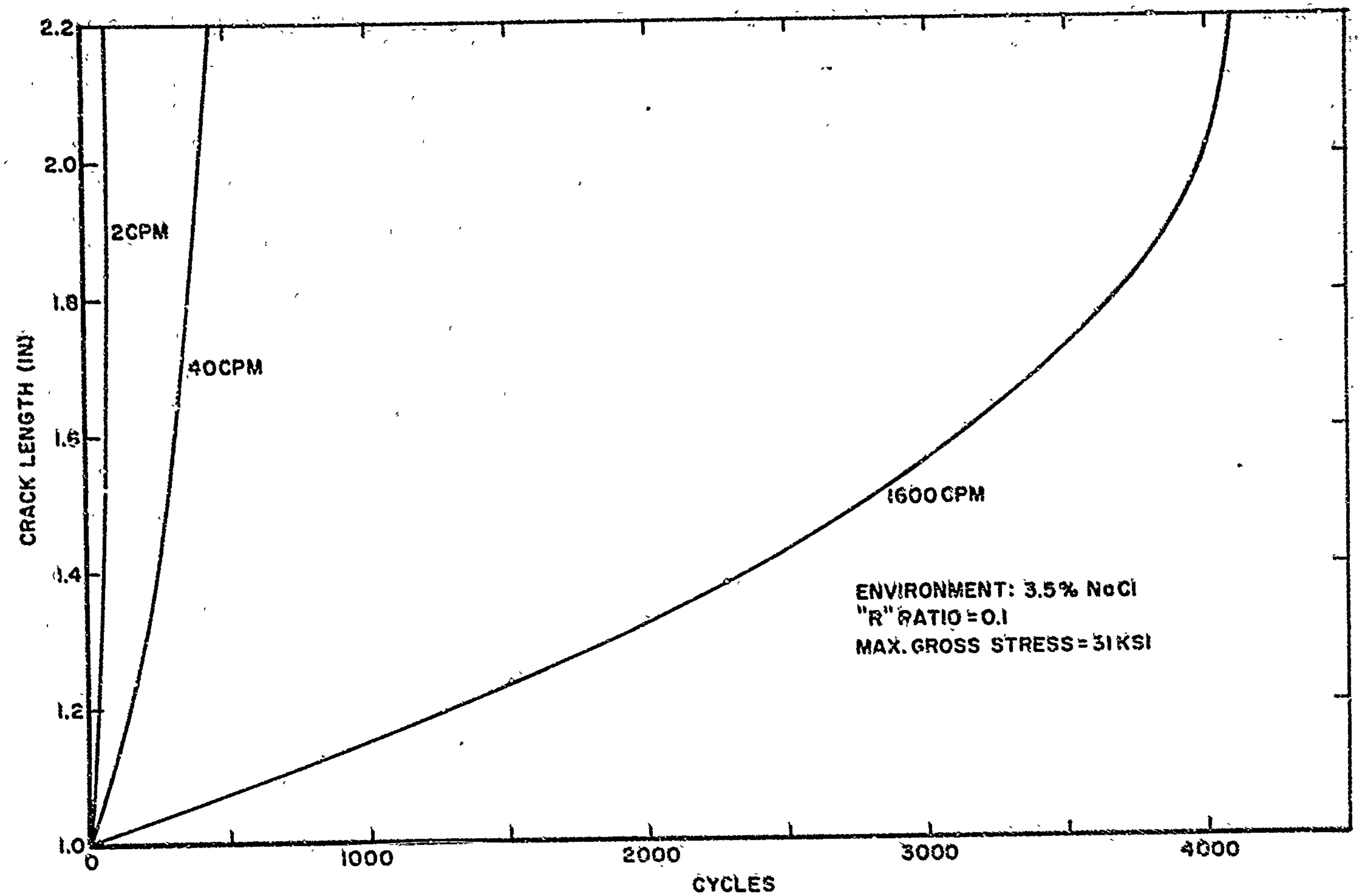

Figure 5. Crack Length vs. Cycles at Various Frequencies in a 3.5 Percent NaCl Solution

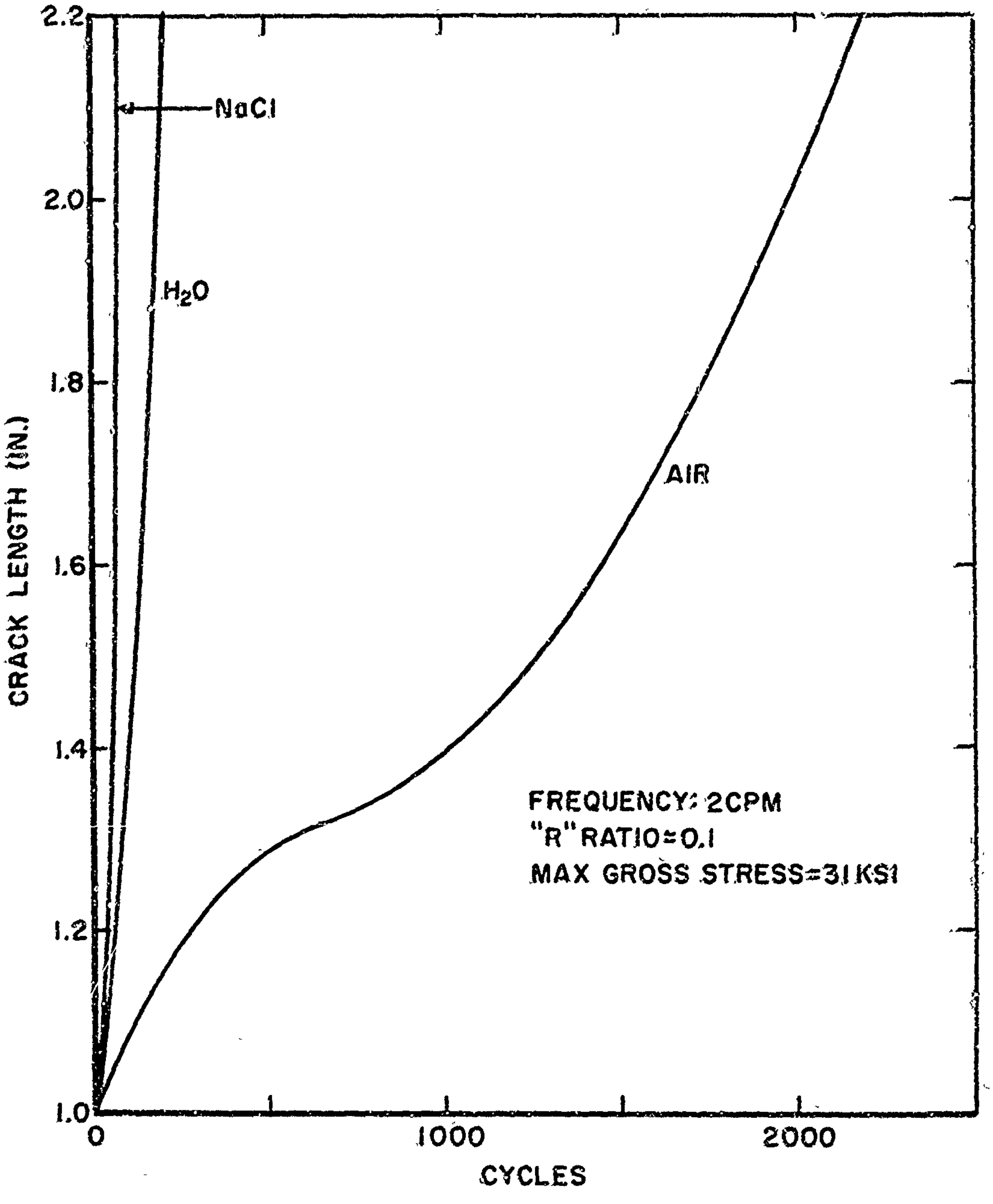

Figure 6. Crack Length vs. Cycles at 2 cpm

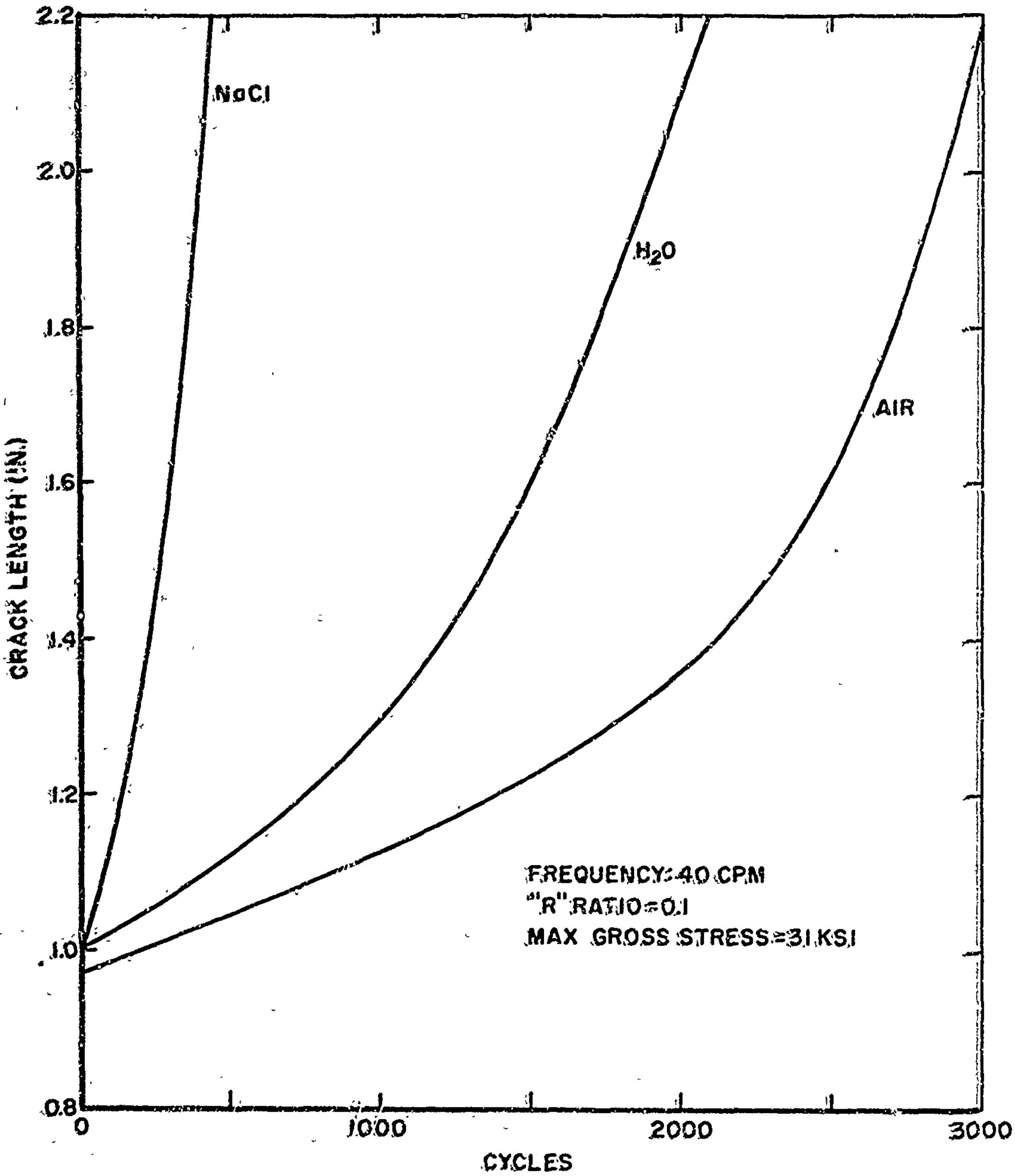

Figure 7. Crack Length vs. Cycles at 40 cpm

produce shorter cyclic life which is understandable considering the sensitivity of the material to SCC. At the lower frequency the crack tip is exposed to stress intensities greater than the threshold SCC stress intensity (K_{ISCC}) for a longer period of time on each cycle. Therefore, the mechanical effects of propagating a crack (an air environment crack propagation) have superimposed upon them the SCC effects of crack propagation. At a higher frequency the time for SCC on each cycle is decreased, and its effect is felt less on each cycle causing a longer cyclic life. At the higher frequency tested, (1600 cpm) SCC contributes less to crack propagation and a still longer cyclic life is observed.

Previous results presented in Reference 2 indicated a reverse relationship between frequency and cyclic life that was noted in this program. However, data in the previous programs was obtained for only two frequencies, 2 and 40 cpm, both of which can be considered low frequencies. Realizing this early limitation, the present program included a greater frequency spectrum; consequently, the results presented herein must be considered correct.

Boeing Airplane Company has shown that the stress intensity at which SCC will occur under dynamic loading is slightly higher than that for static loading and is related to the loading rate. See Reference 4. At lower loading rates in a 3.5 percent NaCl solution, pop-in occurred slightly above the static K_{ISCC} limit. As the strain rate was increased, the first crack movement occurred at a higher stress intensity. These results of Reference 4 tend to confirm the findings in this investigation that lower frequencies (lower loading rates) are accompanied by greater crack per cycle.

If the mechanism of subcritical fatigue crack growth is a mechanical phenomenon, tests in 3.5 percent NaCl solution and H_2O should produce similar results. Referring to Figures 6 and 7, it can be seen that both a N: Cl solution and H_2O environments decrease the crack growth life as con pared to an air environment. However, the degrading effect of the H_2O is less than the degrading effects of 3.5 percent NaCl solution. At 40 cpm the effect of the NaCl is considerably more severe than the H_2O while at 2 cpm only a moderate difference is noted between the NaCl solution and the H_2O.

From these results no definite statement can be made concerning the mechanism of environmental subcritical crack growth under fatigue loading. The inability to separate variables is partially attributed to the small range of frequencies over which data was generated for the three environments. Although there is a factor of 20 between the two lower frequencies, the two frequencies can still be classified as low frequency.

SECTION VII

CONCLUSIONS

From the limited number of tests conducted under the various combinations of frequency and environment, the following conclusions can be drawn:

1. The stress level used for precracking SCC specimens can affect the test results. Consequently, the same procedure used for the preparation of precracks for fracture toughness specimens (ASTM-STP-410) should be used in the preparation of precracks for SCC testing.

2. Subcritical fatigue crack growth rates in a corrosive environment for Ti-8Al-1Mo-1V in the duplex annealed condition are frequency dependent with lower frequencies causing shorter cyclic lives.

SECTION VIII

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4. ARPA Coupling Program on Stress-Corrosion Cracking, NRL Memorandum Report 1834, November 1967.

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